# Current sheet dynamics in the VINETA II magnetic reconnection experiment

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## Abstract

A central issue in magnetic reconnection research is the detailed understanding of the evolution of the current sheet which forms along an X-line between opposed magnetic fields. Its time evolution as measured in the VINETA II guide field reconnection experiment are presented, showing a strong distortion of the sheet along the sheared magnetic field lines. The observed fluctuations are found to be strongly correlated with the local current density and are qualitatively similar to those identified in the toroidal magnetic reconnection experiment (MRX).

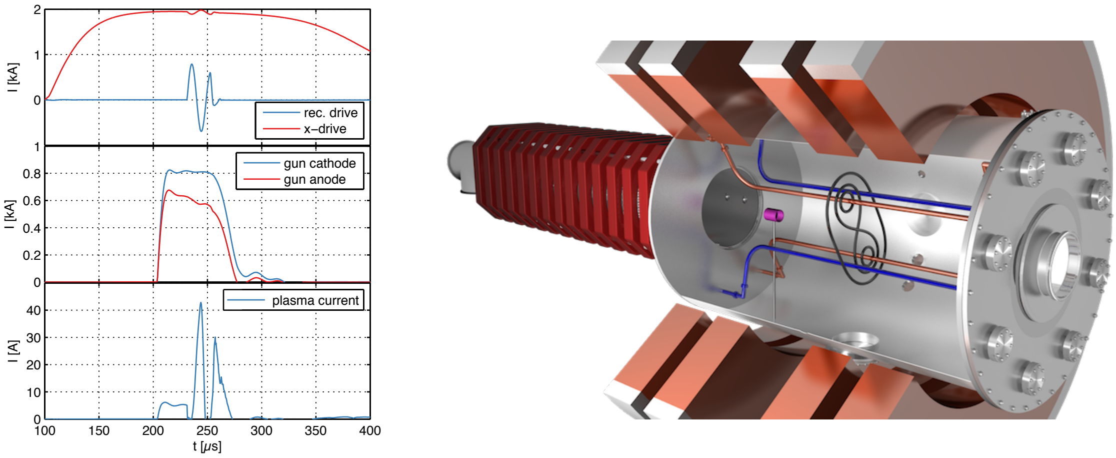


Figure 1: Left: externally applied currents to the X-drive and reconnection drive wires, plasma gun currents and total induced plasma current over a reconnection shot. Right: CAD drawing of VINETA II with its current drives (blue and copper), external guide field coils, plasma gun (pink) and sample in-plane field lines (black).

## Experiment

VINETA II is a cylindrical guide field reconnection experiment in a well-controllable laboratory environment, as depicted in fig. 1 (right). Two parallel axial wires (shown in copper with $I < 7$ kA) create a stationary figure-eight in-plane magnetic field with an X-line along the central axis, as indicated by the black lines. The ratio of the guide field supplied by the large external coils to the in-plane field is typically $B_g/B_{ip}$=3-50. An axial inductive electric field is created by an additional pair of wires (red) which are driven with a sinusoidal current. This

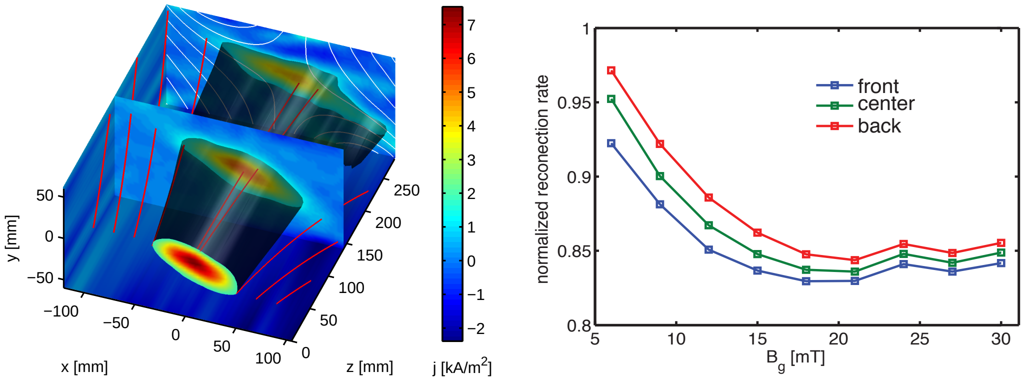


Figure 2: Left: current density in 3 azimuthal planes showing the distorted 3D structure of the current sheet. The black surface encloses the same axial current in each plane. Sample field lines are shown in red, their in-plane projection in white. Right: normalized reconnection rate in the three planes for different guide fields.

induces a plasma current in a narrow current sheet near the X-point, thus driving reconnection. The currents through all systems over a single shot is shown in fig. 1 (left). The large number of electrons required for high sheet current densities ($j < 50\,\mathrm{kA/m^2}$) is supplied along the X-line by a plasma gun (pink). A background plasma is supplied by rf heating ($n < 10^{18}\,\mathrm{m^{-3}}$, $T_e < 3\,\mathrm{eV}$). The spatio-temporal evolution of magnetic fields, currents, densities and electron temperatures are recorded by scanning the azimuthal plane over several hundred highly reproducible discharges. The experiment's unique modularity allows for separation of the current sheet formation from the reconnection fields, enabling a disentanglement of the roles of the magnetic field topology, current sheet and plasma profiles.

**Reconnection dynamics**

When the axial inductive field of the reconnection drive points towards the plasma gun, a significant current is measured within the volume and the external current return wires. For the time point where the total current peaks ($t = 245\mu$s in fig. 1), the local current density as measured in 3 axially separated planes is shown in fig. 2 (left). The red lines are the measured magnetic field lines which result from the guide field superimposed with the in-plane field (shown as white lines), additionally modified by the presence of the localized plasma current. The surface encircles the same total current in each plane and illustrates the distortion of the initially circular current sheet near the plasma gun to a shape which is strongly elongated along the outwards pointing separatrix. Comparison of the current sheet shape with the mapping of the plasma gun aperture along the magnetic field at different guide field to in-plane field ratios shows that to first order, these quantities match well. The presence of a time-varying current sheet gives rise to a decrease of the applied axial inductive electric field at the X-point, thus

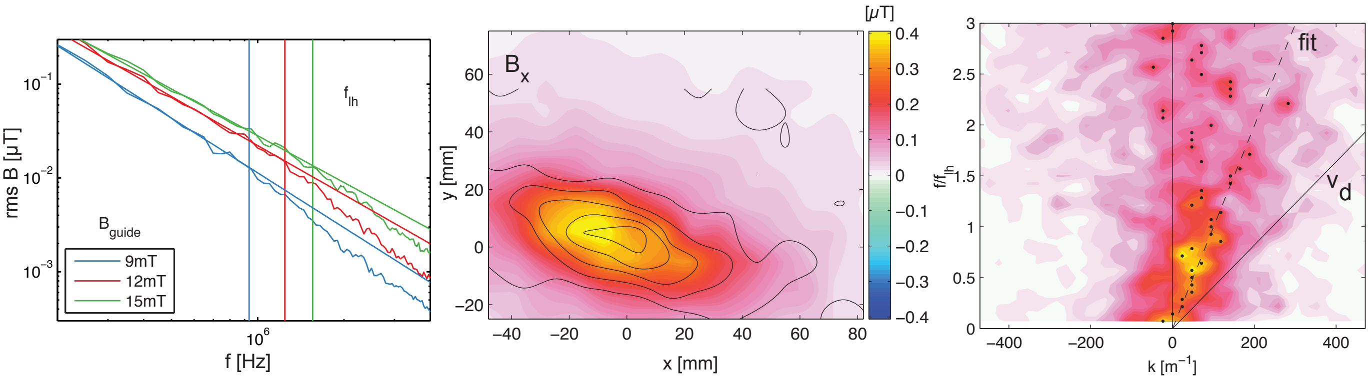


Figure 3: Left: averaged spectra in current sheet center at different guide fields. Center: local fluctuation amplitude (colors) and contours of current density. Right: statistical dispersion relation with a linear fit up to the lower hybrid frequency and the mean drift velocity for reference.

slowing the movement of the field lines, quantified by the (normalized) reconnection rate $R = E/E_{vac}$. The measurement of this rate in the three planes under variation of the guide field is displayed in fig. 2 (right). Especially at low guide fields where the distortion of the current sheet is high, an axial gradient in the reconnection rate is observed, requiring a complex three-dimensional structure of the field lines to match the observations. Upcoming measurements with a new three-dimensional probe positioning system are expected to further clarify this point.

**Magnetic fluctuations**

Magnetic fluctuations have been recorded by amplified miniature magnetic pickup loops capable of picking up fields down to the nT range at frequencies up to 5 MHz. Fluctuations are consistently observed within the current sheet across the entire parameter range, showing a strongly incoherent and broadband behavior. Fig. 3 (left) shows the averaged spectra over 100 shots in the current sheet center at different guide fields. A double power law is observed, with break in spectral indices between $f^{-1.7\pm0.2}$ and $f^{-2.5\pm0.1}$ near the lower hybrid frequency, which shifts with the total magnetic field. The majority of the fluctuation energy is observed in the components perpendicular to the guide field, indicating transversal behavior of the excited fluctuations. The fluctuation amplitude is observed to have excellent spatial correlation with the local current density, as seen in fig. 3 (center), with fluctuation levels of typically $B/B_0$=$10^{-3}$. The fluctuation amplitude also scales with the temporal change of the current density as it peaks during a reconnection shot. The coherence length along the magnetic field is around 2 cm, making a full dispersion analysis difficult. However, a statistical two-point dispersion relation [2] can be reconstructed from a probe pair at close separation ($d$=5 mm), as shown in fig. 3 (right). The excited waves are seen to propagate in the electron flow direction, and a linear fit up to the

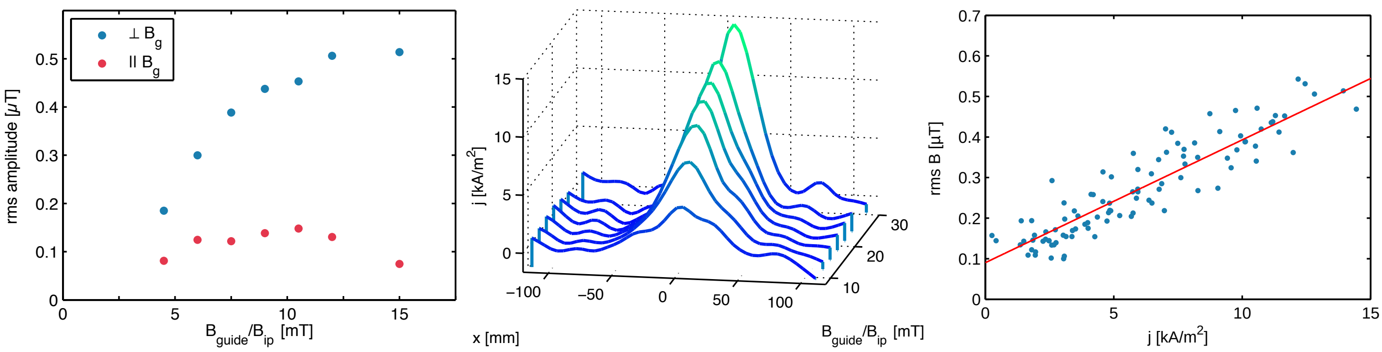


Figure 4: Left: central fluctuation amplitude in parallel and perpendicular to $B_g$ over the guide field ratio. Center: current density profiles at the same guide field ratios. Right: local fluctuation amplitude over local current density across different guide fields and spatial points.

lower hybrid frequency (above which the phase becomes random) shows that the phase velocity is roughly twice the mean electron drift velocity calculated from $v_d = j/ne_0$.

Fig. 4 (left) shows the fluctuation amplitude in the current sheet center when varying the guide field ratio. At higher guide fields, the perpendicular component increases until it saturates at high guide fields. The parallel fluctuations, on the other hand, remain unchanged, again showing the transversal nature of the fluctuations. The behavior of the perpendicular component can be understood by observing the modification of the current sheet profile as shown in fig. 4 (center), which becomes narrower at high guide fields and low magnetic shear. Plotting the local fluctuation amplitude over the local current density shows once again that these two quantities are strongly correlated.

Comparing these results to fluctuations observed in the toroidal MRX experiment shows qualitatively similar tendencies, despite strong differences in geometry, time scale and parameter regime. The fluctuations are broadband below the lower hybrid frequency and propagate with the electron drift velocity. This drift, in contrast to VINETA II, is mainly perpendicular to $\vec{B}$ and has been suggested to drive the modified two-stream instability [3]. The fluctuation amplitude is also observed to have a guide field dependency related to a modification of the current sheet, and is generally higher when the local current density increases.

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## References

[1] Bohlin, H., Von Stechow, A., Rahbarnia, K., Grulke, O., Klinger, T., Rev. Sci. Instrum **85**, 23501 (2014)

[2] Beall, J. M., Kim, Y. C., Powers, E. J., Journal of Applied Physics **53** (1982)

[3] Ji, H., Terry, S., Yamada, M., Kulsrud, R., Kuritsyn, A., Yang Ren, Phys. Rev. Lett. **92**, 115001 (2004)